

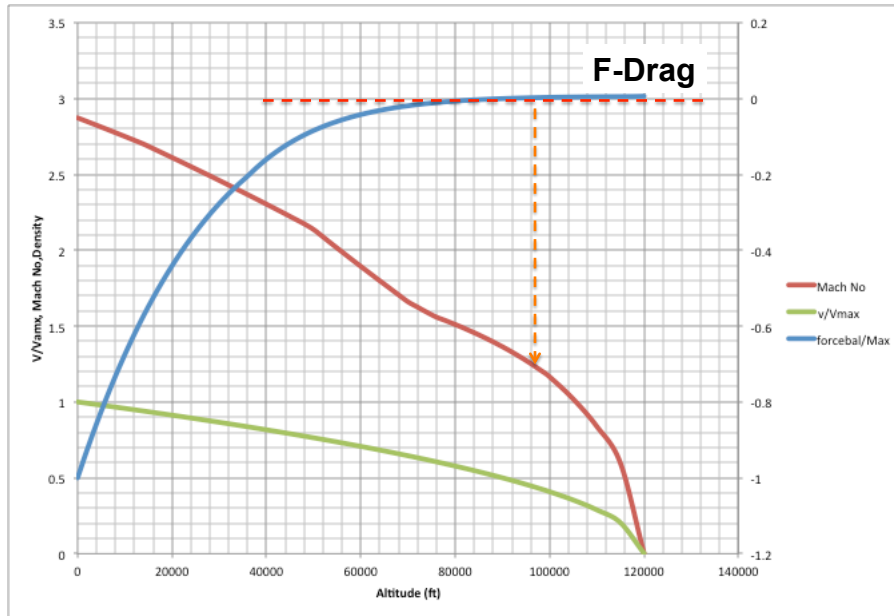
## Sky Dive

- 24 miles  
(126,700ft)
- 833.9 mph  
(1221 fps)
- 9 sec
- Ref: AP



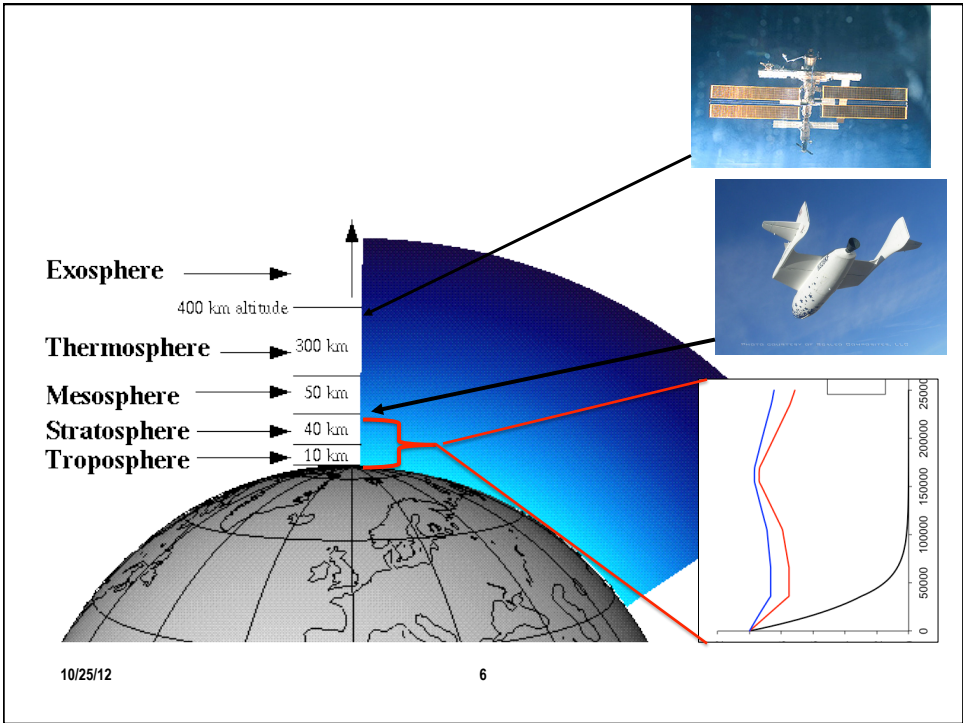
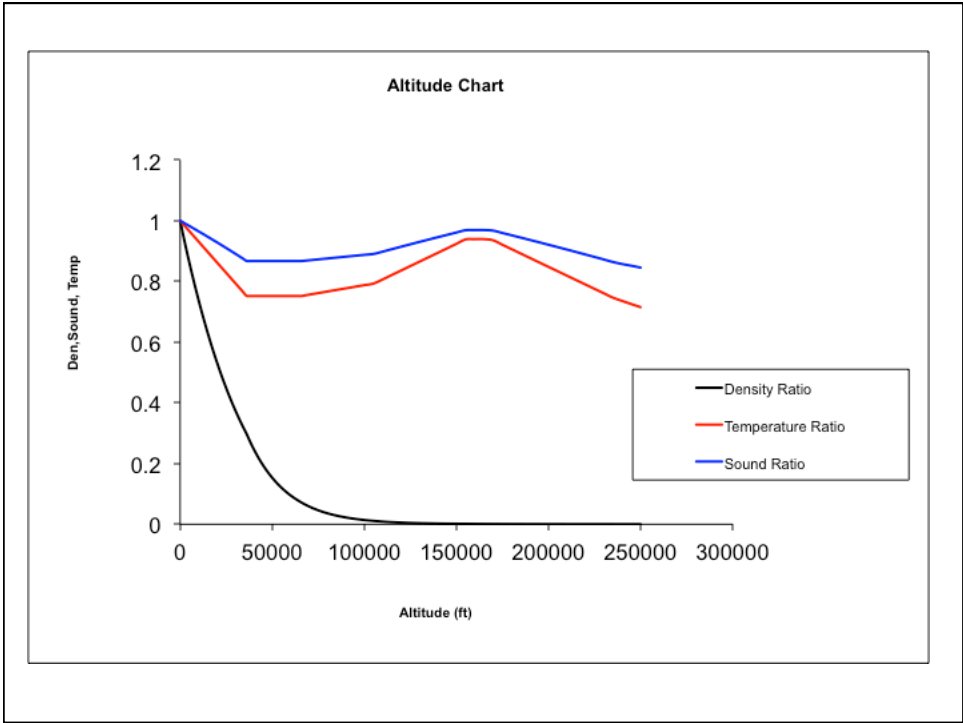
## Is this possible?

- What do we need to know?
- Laws (Newton's)
  - $F = ma = mg$
- Conservation Laws (Energy)
  - Potential Energy =  $mgh$
  - Kinetic Energy =  $.5 \cdot m \cdot v^2$
  - Drag Force =  $.5 \cdot C_d \cdot \rho \cdot \text{Area} \cdot v^2$



Hdrop	h	v_accel	v/Vmax	drag	force bal	Mach No
0	120000	0	0	0	500	0
2000	115000	567.4504	0.204124	26.20627	473.7937	0.597004
4000	110000	802.4961	0.288675	66.46772	433.5323	0.838776
6000	105000	982.853	0.353553	126.8637	373.1363	1.01932
8000	100000	1134.901	0.408248	213.5042	286.4958	1.165677
10000	98000	1190.294	0.428174	257.9027	242.0973	1.21105
12000	96000	1243.222	0.447214	309.0612	190.9388	1.253373
14000	94000	1293.986	0.465475	368.0195	131.9805	1.292626
16000	92000	1342.833	0.483046	435.5119	64.48806	1.329564
18000	90000	1389.964	0.5	512.9608	-12.9608	1.36417
20000	88000	1435.549	0.516398	601.7271	-101.727	1.396823
22000	86000	1479.73	0.532291	703.2946	-203.295	1.427565
24000	84000	1522.629	0.547723	819.269	-319.269	1.456719

$$\text{Time} \sim h/v_{\text{avg}} = 30,000 \text{ ft} / (1300 \text{ ft/s} + 0 \text{ ft/s}) / 2 = 45 \text{ sec}$$



## Mass and Weight

- Mass = Quantity of matter in the object.
- Weight = force upon an object due to gravity

In fact, weight =  $mg$

- Often weight and mass are used interchangeably in every-day life, **but** there is a fundamental difference.
- In outer space, there is no gravity so everything has zero weight. **But**, things still have mass.

## Mass and Weight continued

- Units:

Standard unit for mass is kilogram, kg. (lbm or slug)

Standard unit for weight is Newton (since it's a force)  
(commonly, pound)

### Clicker Question

A 10 kg bag of apples weighs one-sixth as much on the moon than on earth because the moon's gravity is one-sixth as much as the earth's.

If you tried to slide the bag horizontally across a smooth table to a friend, is it one-sixth as easier on the moon than on earth? (ignore friction)

A) Yes

B) No

Answer: B

No! The same horizontal force is needed, since the mass (inertia) of the bag is the same.

### Newton's Second Law of Motion...

#### (i) Acceleration is caused by a net force

e.g. Kick a ball into air: what forces acting, causing what motion?

First: accelerates from rest (i.e velocity from 0 to finite) due to your sudden kick.

While in air: velocity continues to change - eventually falls to the ground due to the (more gradual) force of gravity.

**Acceleration ~ net  
force**

~ means, "directly proportional  
to"

Twice the force on same object, gives  
twice acceleration

## Newton's Second Law of Motion...

The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object.

$$F_{net} = ma$$

## Clicker Question

In a vacuum, a coin and feather fall side by side, at the same rate. Is it true to say that, in vacuum, equal forces of gravity act on both the coin and the feather?

- A) Yes
- B) No
- C) There is no gravity inside vacuum

Note: Mass of the coin is NOT equal to Mass of the feather



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### Clicker Question

In a vacuum, a coin and feather fall side by side, at the same rate. Is it true to say that, in vacuum, equal forces of gravity act on both the coin and the feather?

A) Yes

**B) No**

C) There is no gravity inside vacuum

*Answer: B*

*NO! They accelerate together because the ratio weight/mass for each are equal ( $=g$ ). There is a greater force of gravity on the coin, but its mass (inertia) is greater too.*


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### Friction

- When surfaces slide or tend to slide over one another, a force of friction resists the motion. Due to irregularities (microscopic bumps, points etc) in the surfaces.

#### **Friction also occurs with liquids and gases – air drag**

eg. Push a box across a floor, applying a small steady force. The box may not accelerate because of the force of friction – it may go at constant speed, or slow down, if you get tired and start pushing less. Only if you increase your force so that it is greater than the frictional force, will the box speed up.

### Question

The captain of a high-flying airplane announces that the plane is flying at a constant 900 km/h and the thrust of the engines is a constant 80 000 N.

- a) What is the acceleration of the airplane?

Zero, because velocity is constant

- b) What is the combined force of air resistance that acts all over the plane's outside surface?

80 000 N.

Since, if it were less, the plane would speed up; if it were more, the plane would slow down. Any net force produces an acceleration.

- c) Now consider take-off. Neglecting air resistance, calculate the plane's acceleration if its mass is 30 000 kg, and the thrust at take-off is 120 000 N.

$$a = F/m = (120\,000\text{ N})/(30\,000\text{ kg}) = 4\text{ m/s}^2$$

### “Free” Fall: accounting for air resistance

- Newton's Laws still apply: in addition to force of gravity, have force of air drag,  $R$  (force).

$$\begin{aligned} F_{\text{net}} &= \text{weight (down)} - \text{air drag (up)} \\ &= mg - \text{Drag} \end{aligned}$$

- Drag - depends on

(i) the **frontal area** of the falling object – the amount of air the object must “plow”

(ii) the **speed** of the falling object – the faster, the more air molecules encountered each second

(ii) Density of Air – Denser more more air molecules encountered



- When the net force is zero,  $\text{Drag} = mg$ , and diver no longer accelerates
  - He/she goes at constant **terminal speed (or terminal velocity)** after this.

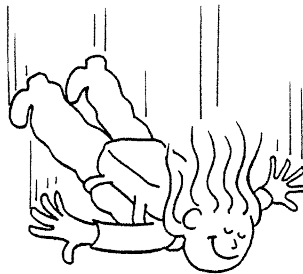
**Question:** How can a skydiver decrease his terminal speed during fall?

**Answer:** By spreading himself out (increase frontal area)

### Question

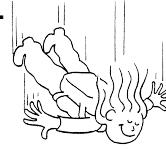
As she falls through the air, her acceleration

1. increases.
2. decreases.
3. remains the same.



As she falls faster and faster through the air, her acceleration

1. increases.
- ✓ 2. **decreases.**
3. remains the same.



**Answer:** Acceleration decreases because the net force on her decreases. By Newton's 2nd law,

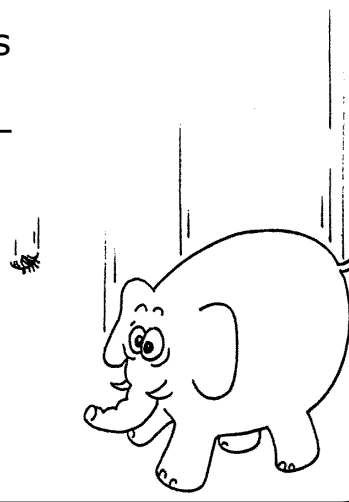
$$a = \frac{F_{\text{net}}}{m} = \frac{(mg - R)}{m}$$

where  $mg$  is her weight and  $R$  is the air resistance she encounters. As  $R$  increases,  $a$  decreases. Note that if she falls fast enough so that  $R = mg$ ,  $a = 0$ , then with no acceleration she falls at constant velocity.

### Question

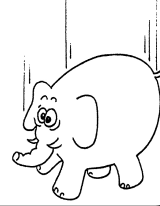
Which encounters the greater force of air resistance—

1. A falling elephant, or
2. A falling feather?



Which encounters  
the greater force  
of air resistance—

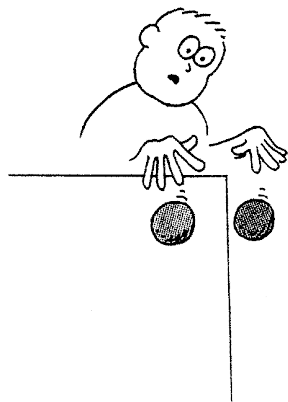
- ✓ 1. **A falling elephant**, or
2. A falling feather?



**Answer: the elephant**

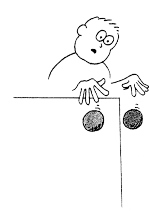
There is a greater force of air resistance on the falling elephant, which “plows through” more air than the feather in getting to the ground. – both resistance and greater mass.

**Clicker Question**



Two smooth balls of exactly the same size, one made of wood and the other of iron, are dropped from a high building to the ground below. The ball to encounter the greater force of air resistance on the way down is

1. the wooden ball.
2. the iron ball.
3. Neither. The force is the same.



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1. the wooden ball.
- ✓ 2. the iron ball.
3. Neither. The force is the same.

**Answer: the iron ball**

Air resistance depends on **both** the size and *speed* of a falling object.

Both balls have the same size, but the heavier iron ball *falls faster* through the air and encounters *greater air resistance* in its fall.

Be careful to distinguish between ***the amount of air drag and the effect of that air drag.***